Simulating the effect of anthropogenic climate change on the Greenland ice sheet

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Goal of this study:
During the development of the coupling of an ice sheet component to the MPI-ESM several decisions had to be made, that potentially could have impacted the model response (First results from the new coupled atmosphere-ocean-ice sheet model of the MPI are presented in the poster of Rodehbeck et al.). Here an attempt is made to estimate, how some of these decisions may have influenced the simulated effect of anthropogenic climate change on the future development of the Greenland ice sheet (GrIS). The coarse resolution version of the AR4 model of the MPI has been used to estimate the effect of different methods to calculate the surface mass balance of the ice sheet as well as the effect of choosing a different ice sheet model. All simulations presented here represent fully 2-way coupled model simulations.

Model setup:
Atmosphere-ocean-vegetation model ECHAM5 T31L19MPIOM-GR30L40/LPJ coupled to:
1. SICOPOLIS (10 km Greenland, R. Grewe) with 3 different surface mass balance schemes:
   - EBM with albedo solely a function of temperature (like in ECHAM5, Vizcaíno et al. 2010), used as baseline setup in this study, spun up with 2 glacial cycles, spin-up from 9 kybp incl. pCO\(_2\) and insolation using EBM scheme, AOGCM accelerated.
   - EBM2 advanced albedo scheme including snow aging (1850 y spin-up branched off from EBM-run).
   - PDD positive degree day scheme (1850 y spin-up branched off from EBM-run)
2. PISM ice sheet (20 km northern hemisphere, Bueler and Brown 2009) with PDD (equilibrium spin up), model results for LGM presented by Bueler and Brown 2009) with PDD (equilibrium spin up), model results for LGM presented by Bueler and Brown 2009), PDD, PDD PISM 20km
3. A set of simulations with EBM2 and a 10 km PISM setup for Greenland (as used in MPI-ESM) is ongoing. The results for MPI-ESM are shown in the poster by Rodehbeck et al.

A 1% scenario up to 4x the preindustrial atmospheric CO2 concentration is used for all model setups. Results presented here are anomalies vs. the corresponding control simulations with fixed preindustrial forcing. All simulations have been spun up with time-varying insolation and pCO\(_2\) values up to 1850.

Summary of the results:
- Relatively strong sensitivity of the evolution of the mass of the Greenland ice sheet on formulation of surface mass balance and on ice sheet model. Typical uncertainties for each of these choices is around 30%
- Weakening of the AMOC reduces mass loss by roughly 30%.
- Glaciers around Baffin Bay have remote effect on West Greenland.
- Moderate changes in Greenland ice volume up to 2100.

Surface mass balance calculated using different schemes

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Year 150 yrs</th>
<th>Year 2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBM</td>
<td>9.6 mSLE</td>
<td>14.4 mSLE</td>
</tr>
<tr>
<td>EBM2</td>
<td>8.6 mSLE</td>
<td>12.5 mSLE</td>
</tr>
<tr>
<td>PISM</td>
<td>14.4 mSLE</td>
<td>20.0 mSLE</td>
</tr>
<tr>
<td>RACM02</td>
<td>15.4 mSLE</td>
<td>22.0 mSLE</td>
</tr>
</tbody>
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Change in ice thickness [m]

- Ice loss is strongest in low lying areas due to enhanced surface melt, the interior gains initially ice due to enhanced snow fall.

Global mean 2m air temperature

The coupled AOGCM shows a warming of 8 K in the 4xCO\(_2\) simulation and in the scenario simulations. The rcp8.5 scenario has been capped at 4xCO\(_2\) in order to avoid artificial effects in ECHAM5. The Greenland ice sheet coupling has negligible effects on the global mean temperature.

Simulating the effect of anthropogenic climate change on the Greenland ice sheet

The baseline simulation shows a mass loss corresponding to a global mean sea level rise of 25 cm after 100 years of stabilization of the CO2 concentration at 4xCO2. The new EBM2 and the PDD scheme show a lower mass loss (approx. 30%). Simulations with identical PDD scheme but different ice sheet model show a stronger response in PISM than in SICOPOLIS. The AOGCM shows a strong weakening of the Atlantic overturning (even without coupled ice sheet). Artificially keeping the overturning close to its present rate leads to strong warming over the ice sheet and stronger mass loss.

Volume of GrIS in CMIP5 scenarios

In year 2100 the mass loss of the GrIS corresponds to a global mean sea level rise of 6.8 cmSLE in the rcp8.5 scenario, 4.4 cmSLE in rcp4.5 and 3.6 cmSLE in rcp2.6. After 2100 the mass loss is strongly accelerating in the rcp8.5 scenario.